Quantitative Side-Scan Research for Sediment Characterization and the Development of a Multibeam Subbottom Profiler

Jerald W. Caruthers
The University of Southern Mississippi
Department of Marine Science
1020 Balch Blvd, Stennis Space Center, MS
phone: (228) 688-7126 fax: (228) 688-1121 email: Jerald.Caruthers@usm.edu

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LONG-TERM GOALS

The long-term goals of this work are to contribute to the understanding of bottom backscatter at high frequencies, provide techniques for determining sediment characteristics based on backscatter, and to support experiments within the context of underwater communications and bottom scattering experiments such as KauaiEx and SAX04. An additional goal, recently established for this project, is to contribute to an improved understand of shallow-subbottom backscatter at mid-range frequencies.

OBJECTIVES

Our main objective is to contribute to the understanding of seafloor backscatter at high and mid-range frequencies. Additionally, in support of bottom scattering projects, another principal objective is to provide wide-area, high-resolution data to describe the nature of the bottom/subbottom and to develop a means of classifying bottom characteristics based on backscatter signals. These objectives require an understanding of the statistical nature of the backscatter signal and how to delineate changes in the bottom based on changes in the statistics of backscatter through the collection of several data sets including KauaiEx and SAX04 data. This work contributes particularly to understanding broad-area, spatial variation of the statistics of backscatter. Often bottom-scattering is determined only for a series of isolated bottom points with little or no spatial connectivity.

APPROACH

The main focus of our work in FY07 was to plan and complete the construct the Multibeam SubBottom Profiler (MSBP) that was initiated late in FY05 by ONR with Defense University Research Instrumentation Program (DURIP) funding. An additional effort was made to finalize work on quantitative side-scan sonar backscattering research.

WORK COMPLETED

Further analyses of data collected for the KauaiEx and SAX04 experiments were carried out. A paper on the Kauai work that was submitted late last year to IEEE Oceanic Engineering is still in review [1]. Resulting from our work in SAX04, the Naval Oceanographic Office (NAVO) contracted with USM to conduct side-scan backscattering research off Orange Beach, Alabama, in connection with work they were conducting in December, 2006. Our role in that exercise was to demonstrate the advantages of

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14. ABSTRACT
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logging and analyzing high-bit-rate backscatter data from their side-scan work. Our work was successful, and, as a result of a briefing we made in August, 2007, of our results, NAVO is undertaking revisions in the logging, analyzing, and databasing from their current 8-bit work and transitioning in the future to 12- / 16-bit side-scan data. Figure 1 is an example of some 8-bit tiff images (captured in the NAVO survey) of repeated passes on a target in a cluttered seafloor environment with analyses given in the caption. Figure 2 shows the extended dynamic range available in the 12-bit data (72 dB dynamic range) we collect versus data extracted from the 8-bit tiff images (Fig. 1) that are ubiquitous in side-scan work. Our 12-bit quantitative data allows our system to be used as a research sonar rather than just as a seafloor image creator (e.g., here, there would be a better chance of understanding the nature of the clutter on the seafloor). A further advantage that it provides is the ability to cover wide areas while producing research-quality data (e.g., here, the spatial extent for statistical analyses of localized clutter and the wider-area changes in the statistics).

NAVO was also interested in our work on the MSBP, and provided additional funding to cover a shortfall we had experienced in the construction of the electronics for the system during this fiscal year. The MSBP has been completed to the point that we were able to conduct a test with a slow tow in August, 2007 (see Fig. 3). A briefing for NAVO on the MSBP is planned for October, 2007. The DURIP funding has been expended and the project closed. The system has not yet been completed for standard towing operations; however, with the remaining funds available on our quantitative sonar grant, the system will be completed (all needed hardware is already on hand) by yearend and a full test will be conducted. We have completed one processing algorithm, and, by yearend, we will have completed two others. We are currently working toward a patent disclosure and an SBA/SBIR proposal. Progress in these endeavors could result in a new buried mine-hunting sonar as well as locating other buried objects such as pile lines and cables.

RESULTS

A paper currently in review [1] discussed a new direct technique to calculate sand-ripple heights (in addition to the routine calculation of wavelengths) from high-frequency backscatter data. The technique assumes Lambert scattering and a sinusoidal profile of the sand ripple. Simulated backscatter from a sinusoidal sand-ripple profile modeled from parameters determined by the technique shows a clear match with the measured backscatter data (Fig. 3). Figure 4 show the averaged Fourier transform of the dual-frequency data and of the single simulation for both. Clearly a backscatter profile simulated from Lambert's rule applied to a pure sinusoid would contain non-linearities. The transform of the simulated backscatter matches, in high fidelity, the measured backscatter transform out to the third non-linear harmonic. A sub-harmonic in the observation not contained in the simulation is a possible indicator of non-linearity in the real profile itself.

Five conference presentations were made covering the following topics: a) statistical and change-detection analyses using quantitative side-scan sonar data [2], b) some processing and dynamic-range issues in side-scan sonar analysis [3], c) prospects and techniques for eddy-resolving acoustic tomography in the eastern Gulf of Mexico [4,5], d) a multibeam subbottom profiler [6]. Reference [6] was published as a proceedings paper. References [2] and [3] demonstrated the value of high-resolution digital data taken by a side-scan sonar and how they can contribute to wide-area seafloor backscatter research. References [4] and [5] were continuations of an effort to establish Ocean Acoustic Tomography as a means of monitoring and contributing to the modeling the rich and important dynamics of the eastern Gulf of Mexico. Reference [5] was a poster presented at an NSF EPSCoR meeting. Reference [6] was the first presentation describing the MSBP.

IMPACT/APPLICATIONS

The University of Southern Mississippi's side-scan sonar collects data for the quantitative basic research and analyses of backscatter at 150 and 300 kHz. The wide-area coverage allows for the recognition and interpretation of backscattering variation that is regionally based, whereas often such variation must be treated as simply random, unconnected statistical sampling. Basing the analysis of probability density functions, as is done in this work, is important because of the importance of PDFs in signal processing, and, therefore, understanding regional variability on the PDFs is an application.

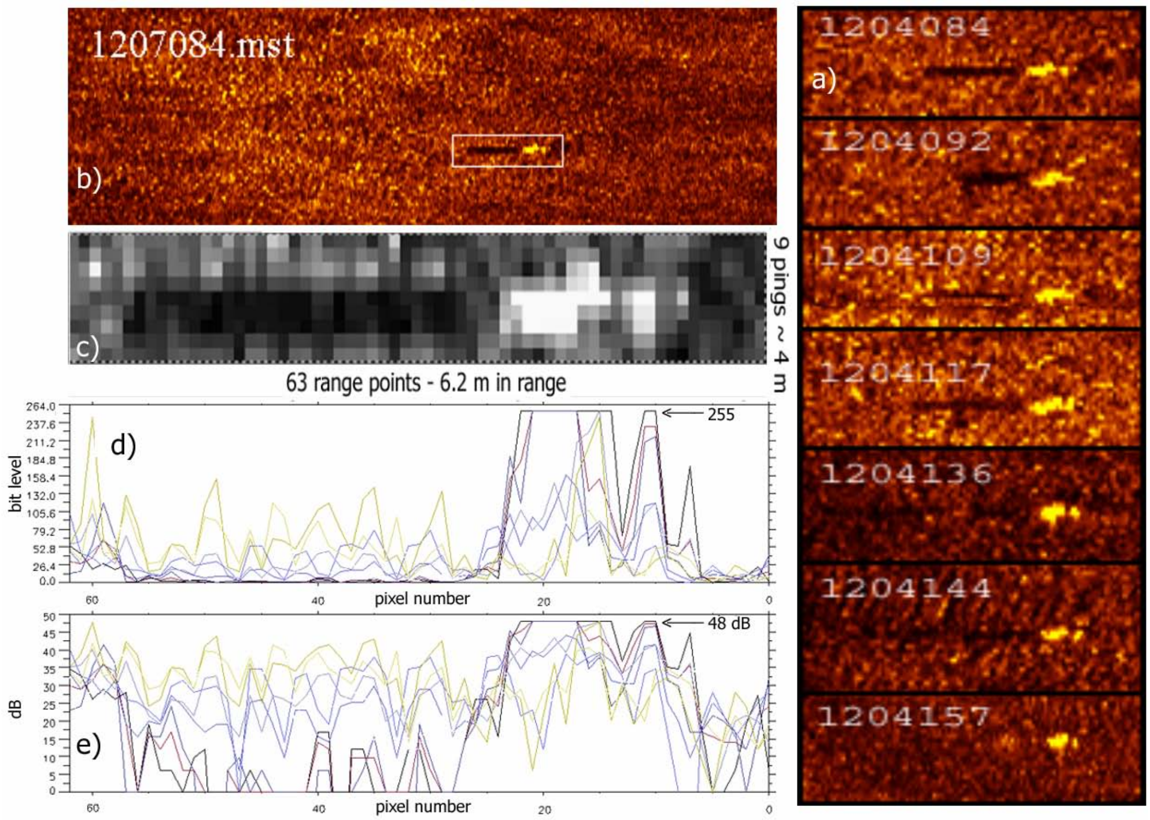

Figure 1: Analysis of side-scan, 8-bit tiff images of an upper-half corner reflector and its shadow sitting on the bottom among seafloor clutter. a) Seven passes of the target. b) A selected target image. c) Over-resolved grayscale of b) above. d) A plot of the scan lines of the available 256 (2^8) levels of pressure extracted from the 8-bit digital in the image. e) The decibel values of those 256 pressure levels (a total dynamic range of 48 dB). First note in d) and e) that some of the lines (yellows and blues) are outside of the target lines. This sets the background reverberation level of the clutter. Second note that the strong returns from the target are clipped and the shadows are set near zero (plus one to get a zero for the decibel value.) Third, how these levels are set in a standard side-scan survey is based on knob twiddling without the prior knowledge of where zero levels or the peak values of a strong target within the operating area will be. What is needed is enough dynamic range to cover the wide range of possibilities – 72 dB for 12-bit data and 96 for 16-bit. Short of that side-scan data extracted from 8-bit tiffs can not be quantitative, research-based data.

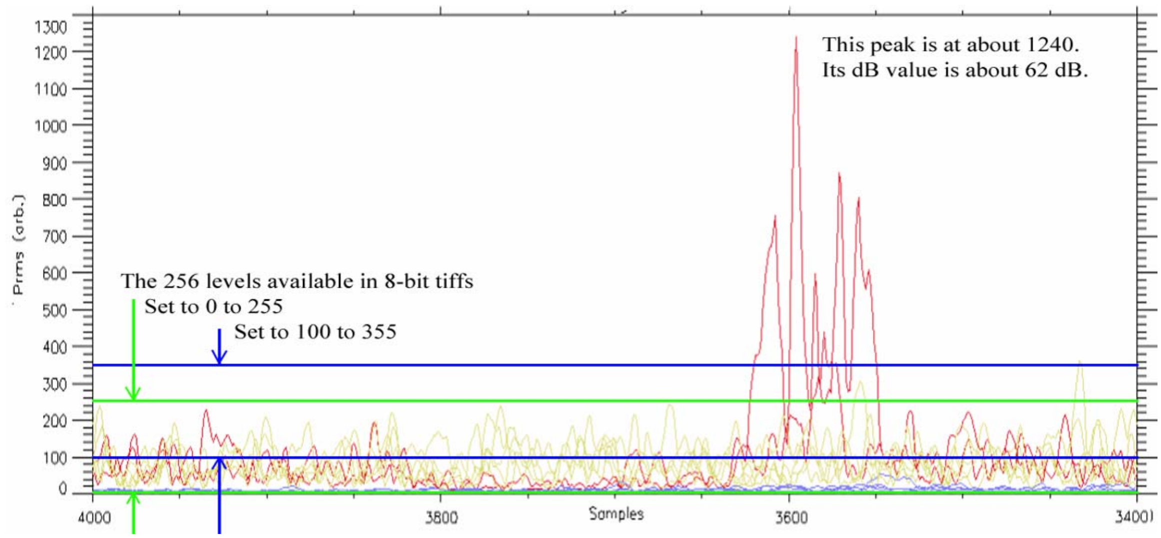

Figure 2: This is a plot of the 12-bit digital data taken with the quantitative side-scan sonar (same hardware and set of pings that produced Fig. 1). However, the output from the towfish was sent to a separate digitizer. Note that it took 1240 levels of the available 4096 (2^{12}) levels to capture the peak (versus the 256 levels that can be extracted from the 8-bit tiffs). Again the yellow lines represent the background clutter levels and the red represents the target, as well as, the target-shadow levels. The light blue data lines are separately measured background noise (no pinging) faintly seen just above the zero level. The heavy, horizontal blue and green lines simulate a priori settings of the knobs from 100 to 355 and 0 to 255, respectively. Clearly the 12-bit data capture what will generally be the full dynamic range of the side-scan data without a priori selection of settings. If one ever thought the 12-bit data would have limitations in the real world, they might select to use 16-bit data with 65536 levels and 96 dB dynamic range.

Figure 3: The Multibeam SubBottom Profiler at the stage of it first underwater test. The MSBP is currently being fitted with a nosepiece, a towing yoke, and a tail horizontal stabilizer.

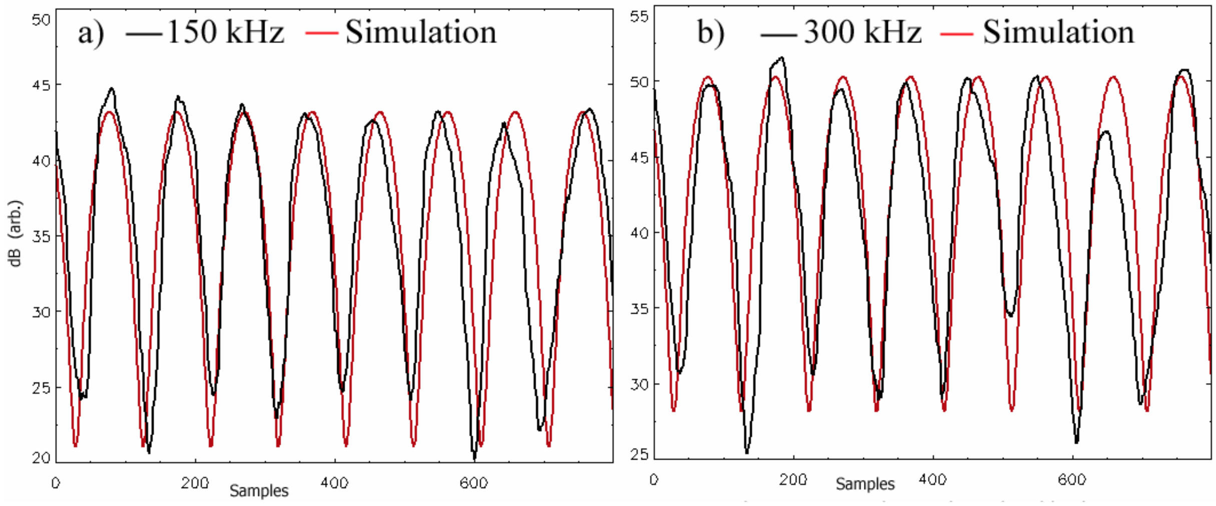

Figure 4: The diagrams show the backscatter from 150 kHz and 300 kHz, respectively. In red is a single simulation for both based on computed Lambert backscatter from a model sinusoidal profile calculated by the technique given in ref. [1]. The maxima are scattering from the front facing slopes and the minima are from the back slopes.

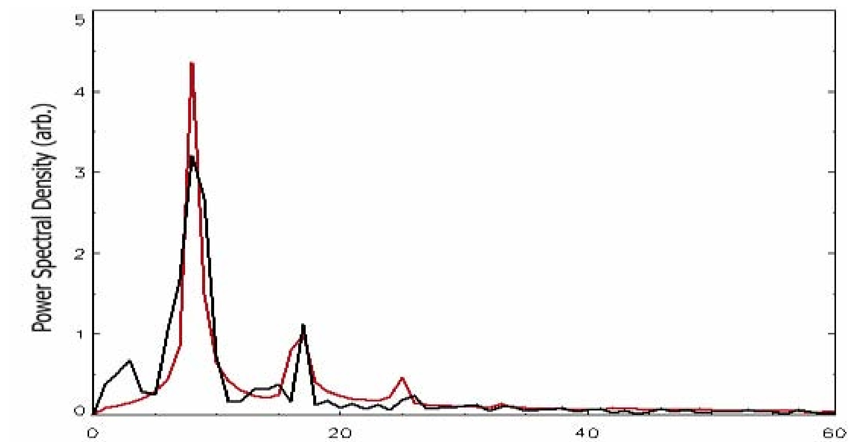

Figure 4: The average Fourier transform of the backscatter data at 150 and 300 kHz (black) and the Fourier transform of the simulated backscatter from the modeled sinusoidal profile (red).

TRANSITIONS

The Naval Oceanographic Office, in support of its Mine Warfare Fleet Support and Technology program, is actively reviewing the need to transition from their current use of side-scan sonar, 8-bit tiff images to 12- and/or 16-bit digital data. The impetus for this new effort is based on results obtained in a joint NAVO/USM survey off Orange Beach, Alabama, and a grant to USM to demonstrate the improvement that can be obtained with the higher bit-rate data. USM was in a position to accomplish this task as a result of work it has done in its ONR Quantitative Side-Scan Sonar Research effort. Additionally, in support of the Mine Warfare Program’s need to support buried mine detection, it has

provided funding to USM to help complete the Multibeam SubBottom Profiler work that was supported primarily by ONR/DURIP.

RELATED PROJECTS

This project includes the continued analyses of data collected in the two ONR projects KauaiEx and SAX04. We just completed a project that supports NAVO with two tasks: A side-scan survey in one of their mine-warfare support ranges and an interest in wide-angle subbottom profiling.

REFERENCES and PUBLICATIONS

[1] J.W. Caruthers, "Analysis of High-Frequency Acoustic Backscatter from KauaiEx with an Emphasis on Computing Sand-Ripple Properties," Submitted to IEEE, J. Oceanic Eng.

[2] J.W. Caruthers, "Statistical and Change-Detection Analyses Using Quantitative Side-Scan Sonar Data," J. of the Mississippi Academy of Sciences, V. 52, p. 125, Feb. 2007.

[3] J.W. Caruthers, "Some Processing and Dynamic-Range Issues in Side-Scan Sonar Analysis," American Geophysical Union Joint Assembly, p. 129, OS51B-07, May 2007.

[4] J.W. Caruthers, D. Nechaev, D.A. Roman, N.A. Sidorovskaia, G.E. Ioup, J. Ioup, M. Yaremchuk, "Prospects and Techniques for Eddy-Resolving Acoustic Tomography in the Eastern Gulf of Mexico," American Geophysical Union Joint Assembly, p. 122, OS44A-02, May 2007

[5] J.W. Caruthers, R. Slaughter, S. Griffin, M.G. Thiele, Jr. "A Multibeam SubBottom Profiler," Undersea Acoustic Measurements: Technology & Results, Heraklion, Crete, Greece, June 2007

[6] J.W. Caruthers, D. Nechaev, D.A. Roman, N.A. Sidorovskaia, G.E. Ioup, J. Ioup, J. Newcomb, “Prospects and Techniques for Eddy-Resolving Acoustic Tomography in the Eastern Gulf of Mexico” 2007 Gulf Coast Post-Katrina Forum, Aug. 2007.